Non-invasive imaging of differing physical forms of dietary fat during digestion in humans.

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Introduction

Knowledge of the distribution of fat within the gastrointestinal (GI) tract is important in understanding the fate of foods rich in fat in the GI tract, and the consequent physiological effects such as fat absorption and increased satiety, and also for the food industry in designing emulsions which are stable or unstable in the GI tract (1). There are many different methods for creating fat only images using MRI (2-5). However not all of these are applicable in the abdomen where volume data needs to be collected within a single breath-hold. Spectral spatial R.F. excitation pulses (6-7) allow FAT only or WATER only images to be acquired without the need for post-processing, and can be used with many different imaging sequences allowing for shorter scanning times.

Sunflower seed contains oil (which is rich in essential fatty acids and vitamin E) within spherical organelles called oil bodies (1-3 μm in diameter) (8). These structures are destroyed during traditional processing to extract and refine sunflower oil, but it is possible to recover and re-disperse them in water to form a milky emulsion. Sunflower oil can therefore be consumed in three distinct forms: (1) as part of the seed; (2) in an emulsion containing oil bodies; and (3) as a processed emulsion where refined oil is emulsified with surfactants. The aim of this work was to compare the fates of these forms of consumed sunflower oil in the GI tract over time using fat and water MRI of the abdomen.

Methods

Scanning was carried out on a Philips 3.0 T Achieva whole body scanner with a SENSE torso coil. The study was approved by the local Ethics Committee and all volunteers gave written informed consent. Four volunteers each attended the study centre on one occasion, after at least a 6-hour fast, and were given a different form of sunflower oil to consume. The different meals were as follows: Meal 1: 100 g of sunflower seeds with 400 g water. Meal 2: 500 g of a suspension of sunflower, water washed, oil bodies (10% lipid wet weight basis (wwb) extracted as per Fisk (8) without the inclusion of sodium phosphate buffer or sucrose in extraction media). Meal 3: 500 g of oil-in-water emulsion (10% lipid wwb) formulated from commercial, sunflower oil stabilized with commercial whey protein isolate (1% dry weight basis (dwb)). Meal 4: As (3) but stabilized with lecithin (1% dwb).

Volunteers were scanned serially after consumption of the meal using the following sequences: (1) Transverse multislice HASTE sequence acquiring 45 contiguous slices to cover the whole abdomen (TR = ∞, TE = 60ms, SENSE = 2, FOV = 400 mm, recon resolution = 0.78 x 0.78 x 7 mm). This sequence was used to image the gastric lumen and help identify the sunflower seeds in the small and large bowel. (2) A 3D T_1-weighted gradient echo sequence with a binomial (1 3 3 1), fat only, excitation pulse to image only fat (matrix size = 640x640, in-plane resolution = 0.625 mm x 0.625 mm, SENSE factor = 2, slice thickness = 2.5 mm, slab thickness = 160 mm, TI = 710 ms, TFE factor = 15.) To image the stomach the 3D block was split up into 4 chunks and scanned in 4, 16 s breath-holds; to minimize stomach motion during each acquisition. For the intestine the 160 mm slab was split up into 8 chunks, each taking 8 s to acquire; however to reduce the overall scan time, 2 chunks were acquired in each 16 s breath-hold. The reduction in time for each 3D chunk was needed as the motion in the small intestine during digestion is faster than the stomach. From the fat only images the different distributions and fates of the fat from the sunflower oil meals were compared over time in the GI tract.

Results

Figure 1 shows a slice from the HASTE and FAT only images of the sunflower seeds (Meal 1) in the stomach. The water preferentially emptied from the stomach for this meal leaving only seeds in the stomach by 100 minutes after meal ingestion. Seeds were seen to have arrived at the ascending colon by 8 hours after this meal was ingested, with the fat only images showing a brighter signal intensity in this region. Figure 2 shows the fat only images at different time points for the oil body emulsion (Meal 2). This meal was seen to gravitationally separate over time in the stomach, however no phase separation of the emulsion was observed. The whey protein emulsion (Meal 3) appeared to be the most stable of all the emulsions showing only a small change in signal intensity across the stomach, which did not alter significantly with time. The lecithin phospholipid emulsion (Meal 4) appeared to phase separate soon after ingestion with a thick fat layer visible on the subsequent fat only images.

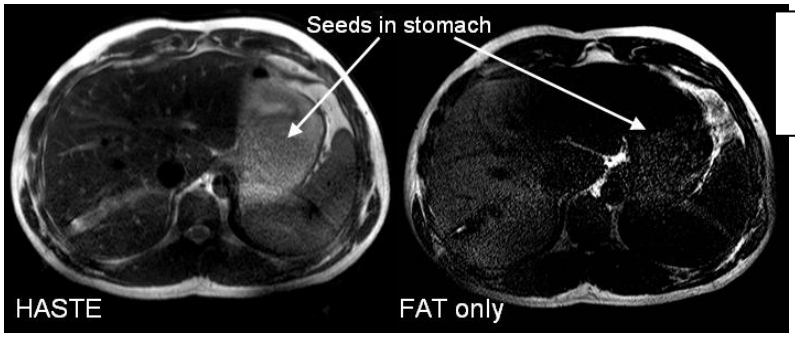

Figure 1. HASTE and FAT only images of a single slice through the stomach after a volunteer had eaten Meal 1.

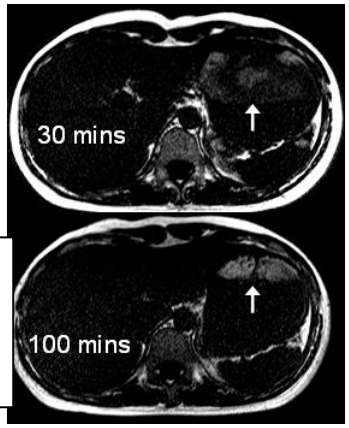

Figure 2. Fat only images of Meal 2 showing gravitational separation of the oil bodies with time (white arrows). Time shown is time from beginning of meal ingestion

Conclusion

The fat only sequence allowed excellent images of oil bodies from plant foods in the GI tract to be acquired in a short amount of time (< 2 mins including wait between breath-holds). Distribution of fat within the GI tract is clearly visible, with particulates of fat also being visible in the small bowel and ascending colon as brighter signal intensities on the FAT images. The different emulsion meals clearly showed different distributions of fat on the fat only images. The lecithin emulsion loses all charge at the low pH in the stomach and therefore loses the electrostatic resistance to coalesce as observed in vivo from the phase separation of the meal. For the whey protein emulsion, the protein has a buffering capacity and the pH of the stomach may only reach 3-4. At this pH the whey protein isolate has a positive charge and the emulsion would be stabilized electro-statically and sterically by the protein (assuming no loss of conformation). The oil body emulsion would also have a positive charge and be stabilized. Limitations of the imaging technique include a large minimum slice thickness, ruling out 2D multi-slice imaging and non-uniform excitation of the fat protons due to poor shimming at the edges of the FOV and where large amounts of abdominal gas are present. This sequence could be applied to monitoring the distribution of fat within both fat emulsions and mixed meals and to monitor movement of fatty particulates within the whole GI tract. This will be important in understanding and controlling fat digestion.

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